Appendix K

Dose Calculations and Hazard Quotients for Functional Groups/Sensitive Species

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Appendix K

EBSL Calculations and Parameters Input Values

K-1. EBSL EXPOSURE EQUATIONS AND PARAMETER DATA BASE

A need was identified for a method to quickly screen sites based on ecologically based values that would remain protective of all receptors potentially present at a site. Basic similarity in receptors across the facility makes it possible to develop INEEL-wide screening levels. The use of INEEL-specific ecologically based screening levels (EBSLs) provides a rational, consistent approach for allowing initial contaminant screening at each site within a WAG.

The purpose of this section is to document the exposure equations, receptors (functional groups), input parameters, and toxicity reference values (TRVs) used to calculate EBSLs for receptors at WAG 4. EBSLs are defined as concentrations of contaminants of potential concern (COPCs) in soil (or other media) that are not expected to produce any adverse effects to selected ecological receptors under chronic exposure conditions. These EBSLs are INEEL specific and are not applicable to other sites. The report compilations are limited to species and contaminants identified as present at the INEEL, and all values were specifically derived based on environmental conditions specific to the INEEL.

Section K-1.1 presents development of EBSLs equations used for both nonradionuclide and radionuclide contaminants at the INEEL. All subsequent information was compiled in such a form as to support the functional grouping approach at the INEEL. Section K-1.2 presents the compilation of input parameters used in the EBSL equations. Section K-1.3 presents the TRVs used to evaluate potential adverse effects to ecological receptors. Section K-1.4 presents the EBSLs calculated for nonradionuclide and radionuclide contaminants.

K-1.1 EBSL Development

EBSLs are calculated by inverting the exposure equations as discussed in this section. Intake or exposure of ecological receptors to contaminants in the environment is generally calculated using basic foodweb models. In the risk assessment process these intake values are compared to TRVs to provide an evaluation of the potential effects to receptors. Manipulation of these equations allows the calculation of a contaminant concentration in a medium that would not be potentially harmful to the receptors with chronic exposure.

INEEL sites potentially contain both radionuclide and nonradionuclide contamination. Determining exposure to each of these types of contaminants requires different modeling. The approaches used to calculate EBSLs for either exposure to nonradionuclides or radionuclides are presented in the following sections.

K-1.1.1 Development of EBSLs for Nonradionuclide Contaminants

K-1.1.1.1 EBSLs for Soil/Sediment Exposure. The major pathways of contaminant exposure at the INEEL include soil/food and water ingestion. Exposure to contamination is expected to occur primarily via direct soil ingestion and food chain biotransfer (i.e., consumption of plant and animal matter containing chemicals derived from soil). Thus, Equation (K-1) is a general exposure equation for receptors.

$$EE_{soil/food} = \frac{[(PP \times C_p) + (PV \times C_v) + (PS \times C_s)] \times IR \times SUF \times ED}{BW} \qquad \text{(K-1)}$$

where

$EE_{soil/food}$	=	estimated intake from ingestion of food and soil (mg/kg body weight-day)
PP	=	percent of diet represented by prey ingested (kg prey/kg diet)
C_p	=	concentration of COPC in prey item ingested (mg/kg prey)
PV	=	percent of diet represented by vegetation ingested (kg vegetation/kg diet)
C_v	=	concentration of COPC in vegetation ingested (mg/kg vegetation)
PS	=	percent of diet represented by soil (kg soil/kg diet)
C_s	=	concentration of COPC in soil (mg/kg soil)
IR	=	total food ingestion rate (kg dry weight/day)
SUF	=	site use factor (affected area/receptor home range [unitless]); defaulted to 1.0 for EBSL calculation
ED	=	exposure duration (fraction of year spent in the affected area [unitless]); defaulted to 1.0 for EBSL calculation
BW	=	receptor-specific body weight (kg).

Equation (K-2) estimates the concentration of COPCs in prey items (C_p).

$$C_p = C_s \times BAF \qquad \text{(K-2)}$$

where

C_p	=	concentration of COPC in prey item ingested (mg/kg prey)
C_s	=	concentration of COPC in soil (mg/kg soil)
BAF	=	prey-specific bioaccumulation factor (mg COPC/kg in tissue/mg COPC/kg soil).

The concentration of COPCs in vegetation (C_v) was estimated using the Equation (K-3).

$$C_v = C_s \times PUF \qquad \text{(K-3)}$$

where

C_v = concentration of COPC in vegetation ingested (mg/kg vegetation)

C_s = concentration of COPC in soil (mg/kg soil)

PUF = plant uptake factor (mg COPC/kg plant tissue/mg COPC/kg soil).

Equation (K-4) combines the previous equations, thus the exposure equation can be rewritten as:

$$EE_{soil/food} = \frac{C_s \times [(PP \times BAF) + (PV \times PUF) + (PS)] \times IR}{BW} \quad \text{(K-4)}$$

where all parameters are as previously defined.

To calculate EBSLs for screening against nonradiological soil contamination concentrations, the target hazard quotient (THQ) will be determined. This is defined as a quantitative method for evaluating potential adverse impacts to exposed populations, and is calculated in Equation (K-5).

$$THQ = \frac{EE_{soil/sediment}}{TRV} \quad \text{(K-5)}$$

where

THQ = target hazard quotient (unitless), established at 1.0 for nonradionuclide contaminate exposure

$EE_{soil/sediment}$ = estimated exposure from soil and/or sediment (mg/kg body weight-day)

TRV = contaminant-specific toxicity reference value (mg/kg-day).

Thus, solving for the concentration of the nonradionuclide contaminant in the soil (Cs) and assuming that when THQ equals 1 that EE_{soil} = TRV. The EBSL for contaminant in the soil is calculated using the Equation (K-6).

$$NR - EBSL_{soil} = \frac{TRV \times BW}{[(PP \times BAF) + (PV \times PUF) + (PS)] \times IR} \quad \text{(K-6)}$$

where

$NR\text{–}EBSL_{soil}$ = WAG-specific EBSL for non-radionuclide contaminants in soil (mg/kg).

Exposure parameters including dietary composition (percent soil [PS], percent prey [PP], and percent vegetation [PV]), home range, temporal and spatial habitat use data (site use factor [SUF] and exposure duration [ED]), soil ingestion rate, food ingestion rate (IR), body weight (BW) and uptake factors (bioaccumulation factors [BAFs], and plant uptake factors [PUFs]) are input to calculate the EBSL. The input values for calculating EBSLs for each functional group/contaminant combination assume that members of the functional groups are exposed to stressors to the maximum extent, perhaps beyond what is actually expected. For example, it is assumed that a raptor captures 100% of its prey from a contaminated site, and that all the prey are exposed to maximum contaminant concentrations at the site. This is similar to the human risk assessment concept of the "maximally exposed individual," a hypothetical individual who is assumed to live and grow his own food at a location of maximum exposure to a stressor. Each parameter is discussed in Appendix K3 in more detail.

K-1.1.1.2 EBSLs for Water Ingestion Exposure. If potentially contaminated surface water exists, the first step was to compare any observed effluent concentrations against water quality criteria or benchmarks that exist in the literature. If the effluent concentration exceeds the benchmark or if no benchmark currently exists, an EBSL for water ingestion was calculated. This EBSL is only applicable for those species that may be obtaining drinking water for terrestrial species. They are not applicable as benchmarks for the health of aquatic invertebrate or other species that might eventually use the surface water. Equation (K-7) is the general equation for dose in mg/kg body weight-day from water ingestion.

$$EE_{water} = \frac{CW \times WI \times ED \times SUF}{BW} \qquad \text{(K-7)}$$

where

EE_{water}	=	estimated intake from ingestion of food and water (mg/kg bodyweight-day)
CW	=	contaminant concentration in water (mg/L)
WI	=	water ingestion rate (L/day).

The water ingestion is found in Equations K-8 and K-9 (EPA 1993).

$$WI = 0.099\ BW^{0.90}\ \textit{(for all mammals)} \qquad \text{(K-8)}$$

$$WI = 0.059\ BW^{0.67}\ \textit{(for all birds)} \qquad \text{(K-9)}$$

where body weight is in units of kg.

To calculate EBSLs for screening against nonradiological soil contamination concentrations, the THQ will be determined. This is defined as a quantitative method for evaluating potential adverse impacts to exposed populations, and is calculated by Equation (K-10).

$$THQ = \frac{EE_{water}}{TRV} \qquad \text{(K-10)}$$

where

THQ	=	target hazard quotient (unitless), established at 1.0 for nonradionuclide contaminate exposure
EE_{water}	=	estimated exposure from water (mg/kg body weight-day)
TRV	=	contaminant-specific toxicity reference value (mg/kg-day).

Thus, solving for the concentration of the nonradionuclide contaminant in the water and assuming that when THQ equals 1 that EE_{water} = TRV. ED and SUF are defaulted to 1.0 and therefore are dropped from the equation.

$$EBSL_{water} = \frac{TRV \times BW}{WI} \tag{K-11}$$

Because of the complexity of water ingestion by reptiles, no general reptilian water ingestion equation is available. It was generally assumed that desert reptiles, such as those found at the INEEL, get their water from prey. Plant uptake of contaminated surface water is also not considered.

K-1.1.2 Development of EBSLs for Radionuclide Contaminants

The method used for relating the amount of radiation to specific biological effects is the radiation dose rate, which is a measure of the amount of radiation energy that is dissipated in a given volume of living tissue. Radionuclide exposure can occur from both external contact and internal ingestion. These issues will be presented separately.

K-1.1.2.1 Internal Radiation Dose Rate from Soil Exposure. Internal radiation dose rate estimates are calculated by assuming that the steady-state whole body concentration is equivalent to the steady-state concentration of radionuclides in reproductive organs using Equation (K-12). This is as presented in IAEA (1992).

$$DR_{internal} = \frac{TC \times ED \times SUF \times ADE \times FA \times 3200\ dis/day\text{ - }pCi}{6.24 \times 10^9\ MeV/g\text{ - }Gy} \tag{K-12}$$

where

$DR_{internal}$	=	internal radiation dose rate estimate (Gy/day)
TC	=	tissue radionuclide concentration (pCi/g)
ED	=	exposure duration (fraction of year spent in affected area) (unitless)
SUF	=	site use factor (affected area/receptor home range [unitless]; defaulted to 1.0 for EBSL calculation
ADE	=	average decay energy per disintegration (MeV/dis)
FA	=	fraction of decay energy absorbed (unitless)

Since tissue levels of radionuclides are derived by multiplying the concentration of radionuclide in soil by a radionuclide-specific concentration factor (CF) for all terrestrial animals or terrestrial plants, the above equation can be rewritten as Equation (K-13).

$$DR_{internal} = \frac{CS \times CF \times ED \times ADE \times FA \times 3200\ dis/day\text{ - }pCi}{6.24x10^9\ MeV/g\text{ - }Gy} \tag{K-13}$$

where

CS = concentration of contaminant in soil ingested (pCi/g)

CF = concentration factor (unitless).

Solving for the concentration of contaminant in soil (CS) and redefining this concentration as an EBSL, the EBSL for internal consumption of radiological contaminants from contaminated soil media is estimated using the Equation (K-14).

$$EBSL_{internal} = \frac{TRV \times 6.24 \times 10^{9}\ MeV/g\text{ - }Gy}{CF \times ED \times ADE \times FA \times 3200\ dis/day\text{ - }pCi} \tag{K-14}$$

where

$EBSL_{internal}$ = internal ecological based screening level for radionuclides in soil (pCi/g)

TRV = toxicity reference value (Gy/day).

Assumptions used in the calculation of the ADE values were for radiations whose energy would be deposited in small tissue volume (ß,a), the FA was set equal to 1. For gamma radiation, the FA was conservatively set equal to 0.3 (30%). This assumption was assumed to be conservative (IAEA 1992). Only radiations with an intensity of 1% or greater were considered, and Auger and conversion electrons were not considered. The ADE values were calculated using Equation (K-15) (Kocher 1981):

$$ADE = \sum_{i=1}^{n} Y_i\ E_i \tag{K-15}$$

where

ADE = average decay energy per disintegration (MeV/dis)

Y_i = yield or intensity

E_i = energy of radiation, for ß = average energy.

CFs for radionuclides are discussed in Appendix J. For EBSL development the CF values for animals are assumed to be 1 for contaminants and receptors unless the reported value is greater (in this case the larger value was used). This is a conservative assumption used to develop screening level values.

K-1.1.2.2 Internal Radiation Dose Rate from Water Ingestion. Water ingestion of radionuclides may occur and will be assessed by using a differential equation [Equation (K-16)].

$$\frac{dTC}{dt} = I - \lambda_1(TC) - \lambda_2(TC) - L \tag{K-16}$$

where

TC = tissue concentration (pCi/g tissue)

I = intake [(pCi/L)(L/g tissue-day)]

λ_1 = radiological decay constant (1/day)

λ_2 = biological loss constant (1/day)

L = other loss (e.g., through urination) [(pCi/L)(L/g tissue-day)].

Conservatively assuming L = 0 and solving for TC at equilibrium (i.e., dTC/dt = 0) gives Equation (K-17).

$$TC = \frac{I}{\lambda_1 + \lambda_2} \qquad \text{(K-17)}$$

The daily ingestion rate of the radionuclide from water, *I*, is calculated using Equation (K-18).

$$I = \frac{CW \times WI}{BW \times 1{,}000\ g/kg} \qquad \text{(K-18)}$$

where

I = intake [(pCi/L)(L/kg tissue-day)]

CW = concentration of the radionuclide in water (pCi/L)

WI = water ingestion rate (L/d)

BW = body weight (kg).

So the tissue concentration due to water ingestion determined by Equation (K-19).

$$TC = \frac{CW \times WI}{BW \times (\lambda_1 + \lambda_2) \times 1{,}000\ g/kg} \qquad \text{(K-19)}$$

The water ingestion is found using Equations (K-8) and (K-9).

Multiplying this equation by (ED × ADE × FA × 3200)/6.24 × 10^9) results in a dose rate analogous to that calculated in Equation (K-13). Solving for the concentration of CW and redefining this concentration as an EBSL, the EBSL for water ingestion of radiological contaminants from contaminated water media is estimated using the Equation (K-20).

$$EBSL_{water} = \left[TRV \times BW \times (\lambda_1 + \lambda_2) \times 1000 \times 6.24 \times 10^9\right] / (WI \times ED \times ADE \times FA \times 3200). \qquad \text{(K-20)}$$

where:

$EBSL_{water}$ = ecologically based screening level for radionuclide ingestion from water (pCi/L).

K-1.1.2.3 External Radiation. External dose rate EBSLs are derived using formulas outlined in Shleien (1992). Dose rate to tissue in an infinite medium uniformly contaminated by a gamma emitter is calculated by Equation (K-21).

$$DR_{external} = \frac{2.12 \times ADE \times C}{\rho} \tag{K-21}$$

where

$DR_{external}$	=	external dose rate to tissue (rads/hr)
ADE	=	average gamma decay energy per disintegration (MeV/dis)
C	=	concentration of contaminant (mCi/cm^3)
ρ	=	density of the medium (g/cm^3).

Solving the equation for the concentration in soil (C) assuming an acceptable dose to animals is 1 mGy/day (0.1 rad/day, which is equal to 4.12E-03 rad/hr) (IAEA 1992) and redefining this concentration as an EBSL, the EBSL for external dose from radiological contaminants in soil is estimated using Equation (K-22).

$$EBSL_{external} = \frac{DR_{external} \times 10^6 \ pCi/mCi}{2.12 \times ADE} \tag{K-22}$$

where

$EBSL_{external}$	=	ecologically based screening level for external exposure to radionuclides in soil (pCi/g)
$DR_{external}$	=	external dose rate to tissue (rads/hr)
ADE	=	average gamma decay energy per disintegration (MeV/dis).

This equation conservatively estimates the dose to burrowing terrestrial functional groups (AV210A, AV222A, M122A, M210A, and M422). This equation also conservatively reflects that these functional groups spend 100% of their time with external exposure. For the nonburrowing functional groups, it is conservatively assumed that they are exposed to 50% (hemisphere) of radiation.

The dose rate for use in the external EBSL calculation is 4.12E-03 rads/hr as discussed above. Contaminant-specific average decay energies and FA values for the radionuclides of concern (Grove Engineering 1996) are presented below:

MeV/Dis:

	α	β	γ
• Ag-108m	0.00E+00	0.00E+00	1.62E+00
• Am-241	5.48E+00	0.00E+00	2.23E-02
• Ba-133	0.00E+00	0.00E+00	4.02E-01
• Bi-212	0.00E+00	2.21E+00	2.39E+00

		α	β	γ
•	Bi-214	0.00E+00	6.44E-02	1.48E+00
•	Co-60	0.00E+00	9.57E-00	2.50E+00
•	Cs-134	0.00E+00	1.57E-01	1.55E+00
•	Eu-152	0.00E+00	5.71E-01	1.30E+00
•	Eu-154	0.00E+00	2.33E-01	1.19E+00
•	Mn-54	0.00E+00	0.00E+00	8.35E-01
•	Pa-234m	0.00E+00	8.20E-01	1.14E-02
•	Pb-212	0.00E+00	9.95E-02	1.17E-01
•	Pb-214	0.00E+00	2.19E-01	2.29E-01
•	Pu-238	5.49E+00	0.00E+00	2.78E-05
•	Pu-239	5.15E+00	0.00E+00	5.66E-05
•	Ra-226	4.77E+00	0.00E+00	6.10E-03
•	Sr-90	0.00E+00	5.83E-01	0.00E+00
•	Th-234	0.00E+00	4.45E-02	8.06E-03
•	Tl-208	0.00E+00	1.60E+00	2.61E+00
•	U-234	4.76E+00	0.00E+00	1.49R-01
•	U-235	4.28E+00	0.00E+00	1.36E-01
•	U-238	4.20E+00	0.00E+00	3.47E-05
•	Zn-65	0.00E+00	2.03E-03	5.66-01
•	Zr-95	0.00E+00	1.16E-01	8.00E-01

K-1.2 EBSL Parameter Input Values

EBSLs were calculated using the models presented in this appendix and species-specific input values (PV, PP, PS, IR, WI, BW, ED, SUF) compiled from the literature. Exposures for each functional group or species incorporate best estimates to reflect species-specific life history and feeding habits. Defaults and assumptions for selecting EBSL soil/sediment and drinking water model input values are given in Table K-1-1. Finalized parameter input values used to model contaminant intake through consumption of food or water by functional groups and individual species evaluated as part of the initial ERA screenings are presented in Table K-1-2. These values have been explicitly developed to reflect INEEL contaminant issues. Individual parameter values and literature sources are discussed in the following subsections.

K-1.2.1 Diet (PV, PP, PS)

Group and individual species diets are represented in the EBSL equations by the sum of three parameters (percent vegetation [PV], percent prey [PP], and percent soil [PS]), constrained to equal 100%. For herbivores, PV is represented by 1 – PS, (where PP = 0). No distinction was made between the types of vegetation consumed. Although some primarily herbivorous species may consume a small percent of its diet as insect prey, this was considered in the trophic assignment as part of the functional grouping criteria (VanHorn et al. 1995).

For carnivores, PP is represented by 1 – PS, (where PV = 0). Values for the fraction of overall diet represented by prey were taken from species specific or representative species diets as reported in the literature.

Dietary composition for omnivores is represented by (PV-PS/2) + (PP-PS/2) + PS = 1 unless PP or PV are 10% or less, in which case, PS was subtracted from the greater of the two. Dietary profiles for functional groups were based on diets for representative species developed from studies conducted at the INEEL and other regional locations (noted on Table K-1-3). Since most dietary studies report only in terms of prey or vegetation material, the dietary fraction comprised of soil was evenly subtracted from prey and vegetation fractions of the diet to account for inclusion of ingested soil without exceeding 1. The number of individual species comprising prey was not considered; however, the contribution of prey items to overall diet was based on relative biomass rather than the most numerous individual components. Dietary composition for functional groups is represented by the species having the largest PS within that group.

The values for PS were taken primarily from soil ingestion data presented by Beyer et al. (1994). Species for which values were presented in Beyer et al. (1994) are limited, so soil ingestion values were assigned using professional judgement to match dietary habits with species most similar to INEEL species.

Finalized EBSL dietary input values and literature sources for functional groups and individual species are presented on Table K-1-3. Further refinement in the diet of individual species and functional groups is beyond the scope of both screening and WAG-level ERA. More detailed dietary models will be implemented in the OU 10-04 ERA (Appendix D1).

K-1.2.2 Body Weight

Body weights (BWs) for mammals, amphibians, and reptiles were extracted from numerous local and regional studies. Body weights for birds were taken primarily from Dunning (1993) unless local or regional values were available. Values were chosen in order of preference for study locale: (1) INEEL, (2) Idaho, (3) Regional (sagebrush steppe in Washington, Oregon, Wyoming, Nevada and northern Utah), and (4) U.S.-wide. Where no distinction in sex was reported, mean adult weights were used. In cases where only separate means for male and female were reported, the average of the two was calculated. In cases where only a range in weights could be found, a median value was used. Functional group weight represents the smallest individual species body weight in the group. Finalized body weights for functional groups and individual EBSL calculations and literature sources are given on Table K-1-4.